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SYNOPSIS: The paper discusses of some results of flexible footings and their models behaviour in the case of loading-unloading cycles applied to them. The revealed effects have been used to explain the causes of some tanks failures. It has been shown that one of the possible causes is the difference between the displacements of the tank bottom and soil under it following unloading and subsequent loading. A simple technique has been proposed to prevent the failures that can be easily applied when constructing the tanks. The application of the technique both eliminates the causes of the failures and greatly reduces the deflections of the tank's bottom thus making it possible to avoid materials and labour intensive footings.

INTRODUCTION

When designing and constructing tanks simplified assumptions on tank-soilbase interaction are introduced. Existing models can not give the adequate description of flexible plate interaction with soilbase. The experiment is the only tool to fully investigate the complicated processes of this interaction. This circumstance made NIIOSP to stage a long-term research program. Some of the relevant results and the discussion are due below.

THE FLEXIBLE PLATES LOADING TESTS

To get a better understanding of the results and conclusions let us consider at first laboratory loading-unloading tests performed on circular flexible plate models on a sandbase. The sandbase was filled in a 4 x 4 x 4 m.testbox without compaction by dropping sand with a grapple from a fixed height. The dencity of the sand was 1.62 t/m^3. The sand was medium-grained (0.5-1.0 mm. fractions amounted to 67%). The 5000 sq.sm plate models were manufactured from steel 5 mm thick as well as from a transparent material 12 mm thick. In the latter case possibility of visual observation of the effect going on in the model-sand contact surface was provided. Jacks were used to apply loads to the central part of the model through a rubber substrate. Each loading stage was retaind till the settlement stabilize. Maximum loads limited by the values that corresponded to the deflections close to the allowed values for flexible footings of structures, e.g. storage tanks. Vertical displacements of the models were measured along their three radii same as displacements of the sandbase surface both under the models and outside them. Evolution of cracks was registered on the sand surface.

DISCUSION OF RESULTS

Consider Fig. 1 depicting a model and the sand surface displacements in the model center following the primary loading-unloading cycle. In the course of loading the model and the sand displacements coincide.

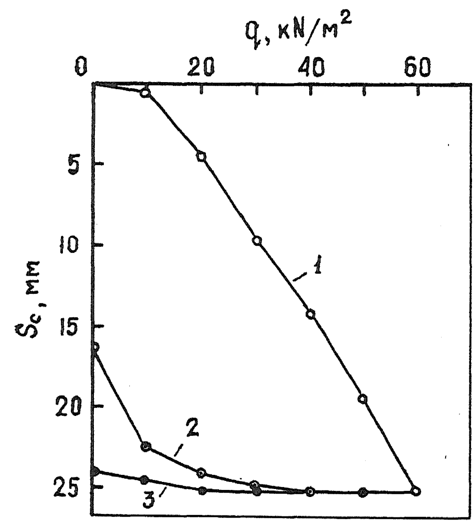

Fig. 1 Displacements of the Model Center and the Sand Surface under It
1, 2- model center 3- sand surface

During unloading the model rises elastically while the sand rebound largely lags behind. This results in formation of a gap between the sand surface and the model during unloading. This gap is shown on Fig. 2. Formation of the gap was registered while testing 2.1x2.1x2.1 m reinforced concrete slabs as well (Palatnikov, E.A. and all, 1978).
Evidently, the gap between the unloaded plate and the soil affects the contact pressure distribution in the course of the subsequent loading making it different from that of the continuous contact between the plate and soilbase. At the beginning of the repetitive loading of the plate contact pressures appears only over a

narrow peripheral ring being rather high so that they may thrust the sand upward inside and outside this ring.

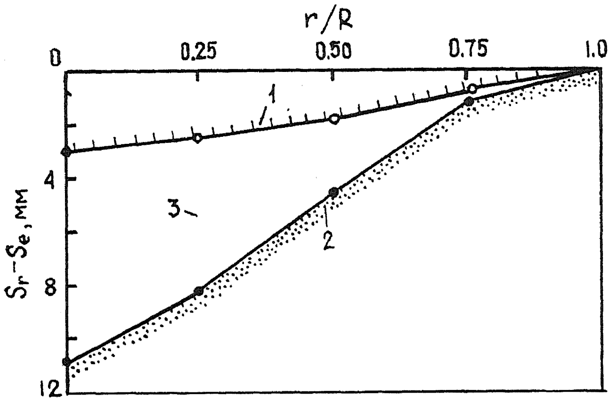

Fig. 2 Position of the Model and the Sand Surface after the First Loading-Unloading cycle

1- model 2- sand surface 3- gap

Such high contact pressures over the periphery of centrally loaded plates caused by repetitive loading was registered in large-scale tests. The data of (Dovnarovitch S.V. and all, 1987) show that plates that successfully endured the primary load may fail under the subsequent load due to the gap between the plate and the soil. Consider Fig. 3 (Bell R.A. and all, 1980) displaying of tanks bottom position of the actual structures after failure: tanks T-270 and T-39 with diameter 52 m. and 46 m. respectively.

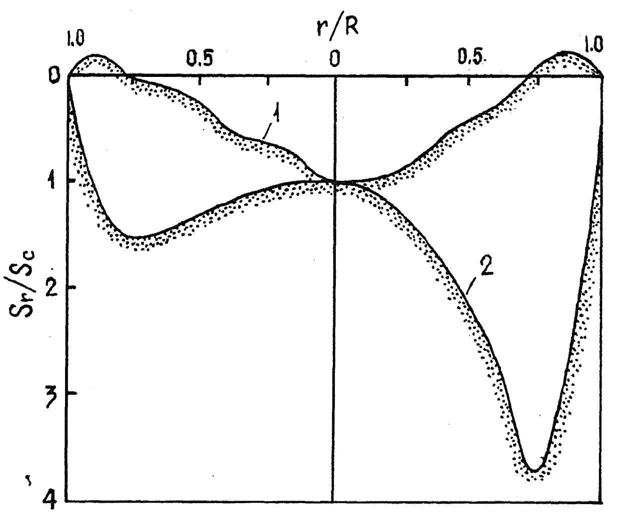

Fig. 3 Differential Settlement of Tanks Bottom after the Accidents

The accident of T-270 happened when it was filled with oil during the service while its water test did not provoke any failure. Such position may be explained as the result of large soil movements under the edges of the tanks where high pressures are caused by repetitive loading. Besides, the effects described above appear both if the tanks rest on soil and on piles. Fig. 4 show vertical displacements of the circular model plate center mentioned above and those of the tank bottom supported by piles (Mohan D. and all, 1978) following first loading, unloading and second loading after remedial underpinning of this foundation.

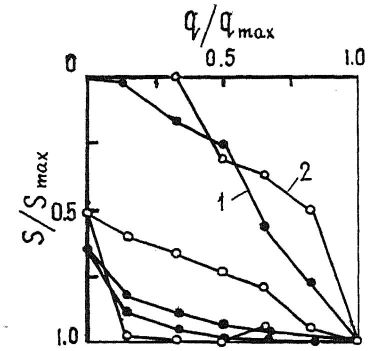

Fig. 4 Relative Vertical Displacements of the Model and Tank Bottom

1- model 2- tank bottom

Rapid settlement growth is observed at the beginning of second loading both in the case of the model and of the tank bottom. It may be explained by the emergence of the soil-footing interaction discussed above.

PROPOSED TECHNIQUE

These and many other results obtained by respective investigations and review of the known data encouraged us to develop a new technique for constructing storage capacity principally different from the conventional ones to prevent accidents and greatly reduce as the differential settlement of structures well as the cost of construction. The technique envisages formation of the tank bottom-soilbase gap and filling said gap with a hardening material. This filling is to be completed during construction operations and water tests before commissioning the storage capacity.
Evidently, the primary load that precedes formation of the gap should be less than the maximum operation load. In the course of the study the proposed technique was elaborated to form and to fill the gap depending on the properties of the soils, the tank size, loads, time-schedule, etc.
The feasibility of the construction technique from the standpoint of the soilbase-structure stability is quite clear. Consider another no less important effect of technique. Look at Fig. 5 showing the deflection of the familiar circular plate model with empty and filled gap. It can be seen that deflections reduce more than twofold if the gap is filled in due time. This makes piles, that would be indispensible for conventional construction tichniques, unnecessary if the described technique is applied. Notably, the proposed technique does not practi-

cally involve any extra cost and is applied without employing sophisticated mashinary and highly skilled specialists.

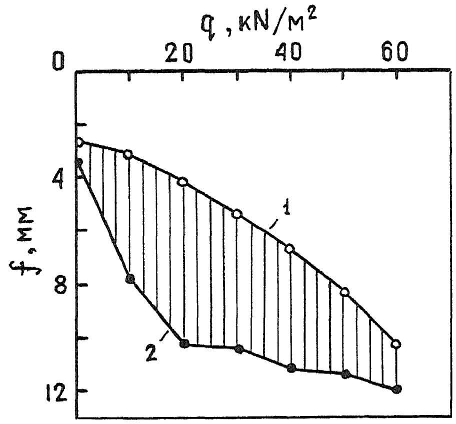

Fig. 5 Deflections of the Models under Second Loading

1- filled gap 2- empty gap

We have touched upon and schematically presented just some of flexible plate-soil interaction features. The problem in question is much more complicated. It is acute in the case of primary loading either. When the plate is loaded centrally, its edges rise above the ground and the contact area reduces while contact pressures grow as compared to the mean pressure with all respective implications, Fig. 6.

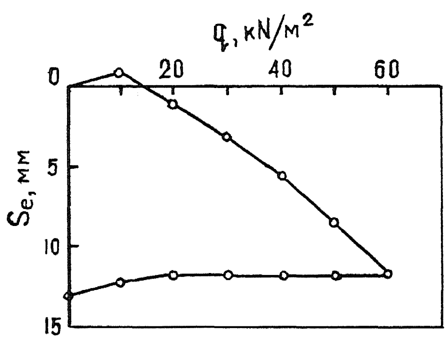

Fig. 6 Displacements of the Model Edge

When the primary load is being reduced the plate edges first do not rise as may be expected, but rather lower. All these and other specific effects might be expected in some cases and sometimes they are even taken into account still they are not only theoretically important and, therefore, the whole problem of interaction of flexible footing with the soilbase needs further thorough investigation.

CONCLUSIONS

The results of tests and field study show that interaction of soilbase and flexible footings of structures, e.g. storage tanks bottom that apply repetitive loads to soilbase may produce specific phenomena that interfere with normal operation of structures. These phenomena, that are not conventionally taken in account, may generate considerable extra deformations and even lead to failures of tanks after the subsequent loading while this very load could be safe in the course of the primary cycle.
The risk of repetitive loading is due to the difference in deformation properties of footing and soil that takes place till the gap between the structure and the soil is formed up when the structure is unloaded. A construction technique is recommended that makes it possible to control formation of the gap between the tank bottom and the soilbase and fill it with a material further on.
The filling increases both stability of the storage tank-soilbase system and reduces more than twofold the deflections of the tank bottom and, respectively, lowers labour and material consumption for erecting the tank footing.

REFERENCES

Bell, R.A. and J.Iwakiri, (1980),"Settlement Comparison Used in Tank-Failure Study," Proc. ASCE, Journal of the Geotechnical Engineering Division, vol. 106, no. GT2, 153-169.

Dovnarovitch, S.V. and A.A.Teplyakov, (1987), "Streses under Rigid and Flexible Footings at the Repeating Loads", Soil Mechanics and Foundation Engineering, no. 1, 29-31,(in Russian).

Mohan D., G.R.S.Jain, R.K.Bhandari, (1978),"Remedial Underpinning of Still Tank Foundation", Proc., ASCE, Journal of the Geotechnical Engineering Division, vol. 104, no. GT5,639-655.

Palatnikov E.A., A.A.Teplyakov, D.S.Baranov, S.V.Dovnarovitch, D.E.Polshin, V.F.Sidorchuk, (1978), "Experimental Investigation of the Flexible Reinforced Concrete Plates on the Sandbase", Proc., GiproNIIaviaprom, vol. 17, 7-21, (in Russian).